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Neutralino Dark Matter and Trilepton Searches in the MSSM

Dan Hooper,[1] Tilman Plehn,[2] and Alberto Vallinotto[3]

[1] *Theoretical Astrophysics Group, Fermilab, Batavia, USA*

[2] *SUPA, School of Physics, University of Edinburgh, Scotland*

[3] *Institut d'Astrophysique de Paris, CNRS-UMR 7095, Université Paris VI Pierre et Marie Curie, Paris, France*

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Abstract

Searches for supersymmetry are among the most exciting physics goals at Run II of the Tevatron. In particular, in supersymmetric models with light charginos, neutralinos and sleptons, associated chargino–neutralino production can potentially be observed as multi–lepton events with missing energy. We discuss how, in the generic TeV–scale MSSM, the prospects for these chargino–neutralino searches are impacted by cosmological considerations, namely the neutralino relic abundance and direct detection limits. We also discuss what an observation of chargino–neutralino production at the Tevatron would imply for the prospects of future direct dark matter searches without assuming specific patterns of supersymmetry breaking.

I. INTRODUCTION

A consensus has formed within the astrophysics community in support of the conclusion that the majority of our universe's mass takes the form of cold, collisionless dark matter [1]. Despite the very large body of evidence in favor of dark matter's existence, the nature of this elusive substance remains unknown. Of the many dark matter candidates to have been proposed, one of the most compelling and most often studied is the lightest neutralino in R-parity conserving models of supersymmetry [2].

Among the most prominent missions of the Tevatron's Run II are its searches for supersymmetry. Results from Tevatron searches for squarks and gluinos [3], neutralinos and charginos [4], stops and sbottoms [5], and the Higgs bosons of the Minimal Supersymmetric Standard Model (MSSM) [6] have each recently been published. While no evidence for supersymmetry has yet been found, in many cases these results represent the strongest limits to date. Although the Tevatron is not well suited to directly place limits on the properties of the lightest neutralino, the results of these other searches can have considerable implications for the nature of this dark matter agent.

One of the prime channels for observing supersymmetry at the Tevatron is associated neutralino–chargino production [7, 8]. These particles can decay to the lightest neutralino and leptons through the exchange of either sleptons or gauge bosons, resulting in events featuring three leptons and missing energy. The results of these searches are somewhat model dependent, but the current results from CDF and D0 can be used to exclude charginos as heavy as approximately 150 GeV in some models, well beyond LEP's chargino mass limit of 104 GeV. By the end of Run II, the Tevatron is expected to exclude selected models with charginos not far below 200 GeV.

Neutralino dark matter can be detected through its elastic scattering with nuclei. Experimental efforts designed to observe such events are known as direct detection. The prospects for this class of techniques depends on the composition of the lightest neutralino, as well as on the masses and couplings of the exchanged squarks and Higgs bosons. Generally speaking, information from collider searches for supersymmetry, whether detections or constraints, can be used to better estimate the prospects for the detection of neutralino dark matter. The relationship between Tevatron and LHC searches for heavy MSSM Higgs bosons and direct searches for neutralino dark matter has been studied in detail elsewhere [9]. Here, we return to this theme, but focussing on searches for trilepton events from associated neutralino–chargino production at the Tevatron (see also Ref. [10]).

In the past, it has been possible to link the Tevatron's trilepton signature to other signatures for new physics, for example the decay $B_s \to \mu\mu$ [11]. Such links rely for example on a correlation between light sleptons and small values of $\tan\beta$ for the chargino and neutralino decays on one hand and the pseudoscalar Higgs boson mass and large values of $\tan\beta$ in flavor physics on the other. Naively, similar correlations should be present when the dark matter candidates annihilate mainly through an s-channel Higgs boson and the trilepton signature requires relatively light supersymmetric scalars. Moreover, one could imagine correlations between these signals in the co-annihilation region, if the lightest slepton is mass degenerate with the lightest neutralino, limiting the visibility of the trilepton channel. However, these fairly obvious correlations rely on a series of assumptions. First, the different MSSM scalar masses have to be correlated. Secondly, the light scalar masses should in some way be linked to the

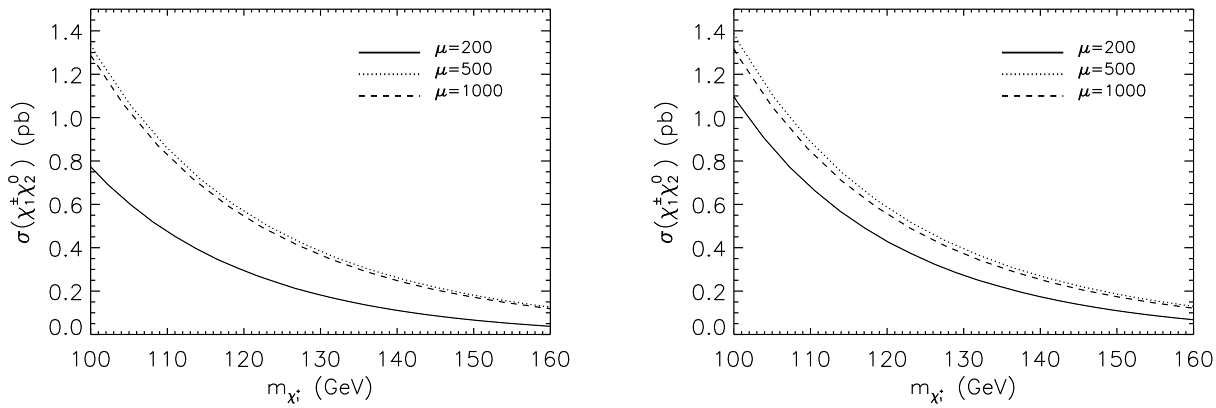

FIG. 1: The cross section for associated chargino-neutralino production at Tevatron Run II, as a function of the lightest chargino mass, for various choices of $\tan\beta$ (3 and 60, in the left and right frames, respectively) and μ [12]. In these Figures we use $2M_1 = M_2$, $m_{\tilde{q}} = m_{\tilde{l_L}} = m_A$ =500 GeV and $A_t = A_b = A_\tau$ =0.

lightest neutralino mass and to the mass difference between the light chargino and neutralino. Last but not least, the dark matter particle should annihilate dominantly through one channel. The aim of this analysis is to determine how much of a correlation between dark matter and Tevatron searches survives if we assume only a TeV–scale MSSM spectrum with no specific patterns of supersymmetry breaking.

This article is structured as follows: In Section II, we discuss the searches for associated chargino-neutralino production at the Tevatron. In Section III, we turn our attention to the thermal relic abundance of neutralinos, focussing on those models within the reach of the Tevatron and the correlation between Tevatron measurements and the neutralino's relic density. In Section IV, we discuss direct detection prospects for such models and the correlations between those and Tevatron observations. Finally, we summarize our results and conclusions in Section V.

II. NEUTRALINO–CHARGINO SEARCHES AT THE TEVATRON

In many supersymmetric models, associated chargino-neutralino production can occur with a cross section on the order of a picobarn at Run II of the Tevatron (1.96 TeV center-of-mass collisions). These particles can each subsequently decay to the lightest neutralino and leptons ($\chi_1^\pm \to \chi_1^0\, l^\pm \nu$, $\chi_2^0 \to \chi_1^0\, l^\pm l^\mp$), either through the exchange of charged sleptons or gauge bosons. This can lead to distinctive trilepton plus missing energy events which, in some supersymmetric models, could be identified over Standard Model backgrounds.

In order for SUSY–trilepton events to be extracted at the Tevatron, however, the underlying supersymmetric model must possess a number of rather specific features. In particular, the $\chi_1^\pm$ and χ_2^0 must both be light. In Fig. 1 we plot the associated chargino-neutralino production cross section as a function of the lightest chargino mass for various values of $\tan\beta$ and μ. The cross section drops rapidly for heavy chargino/neutralino masses. Additionally, in order to be identified at the Tevatron, $\chi_1^\pm$ and χ_2^0 decays must each occur with large branching fractions to

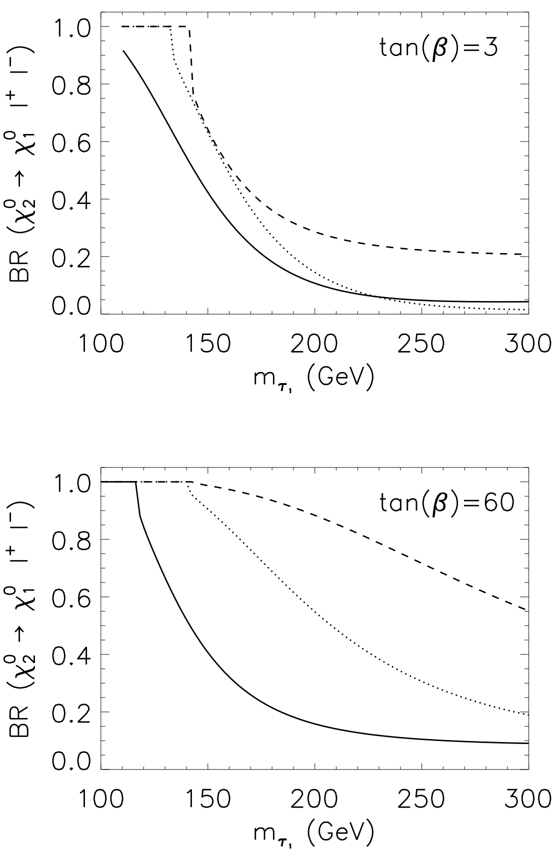

FIG. 2: The branching fractions of χ_2^0 and $\chi_1^\pm$ decays to final states with charged leptons, as a function of the lightest stau mass and for $\tan\beta = 3, 60$. The three lines denote μ =200 GeV (dashed), 500 GeV (dotted) and 1 TeV (solid). We have also used $2M_1 = M_2$ =140 GeV, $m_{\tilde{q}} = m_{\tilde{l}_L} = m_A$ =500 GeV and $A_t = A_b = A_\tau$ =0. In order for the combination of $\chi_2^0\chi_1^\pm$ to decay mostly to final states with three charged leptons, the lightest stau (possibly along with other charged sleptons) must be rather light.

charged leptons, which means that the supersymmetric mass spectrum is arranged such that chargino and neutralino decay primarily to charged sleptons rather than to (off-shell) gauge bosons or squarks, each of which lead to significant branching fractions to jets. Furthermore, WZ production leads to a Standard Model background of trileptons plus missing energy from which any SUSY-trileptons must be separated. To accomplish this, the analyses of CDF and D0 each include kinematic cuts on observables like $m_{\ell\ell}$, designed to remove backgrounds. They reduce the efficiency for supersymmetric events with charginos and/or neutralinos decaying through gauge bosons essentially to zero.

To ensure large branching fractions for charginos and neutralinos through slepton exchange, the lighter sleptons must be quite light. To avoid large neutralino or chargino branching fractions to neutrinos, the sneutrino masses (along with the left handed charged sleptons) must be somewhat heavier. Unless we want to break the $SU(2)$ symmetry between charged slepton and sneutrino masses, this means the lightest charged slepton should be dominantly right handed, independent of unification assumptions. In Fig. 2, we plot the branching fractions of charginos

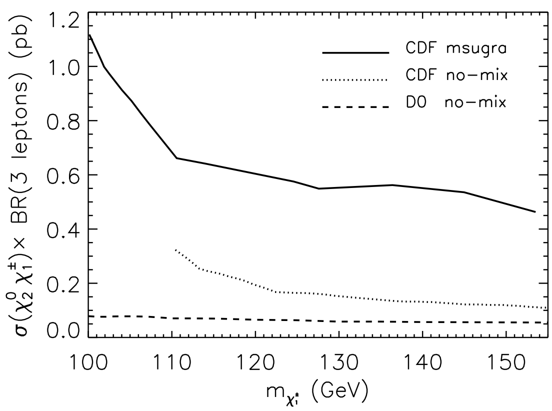

FIG. 3: The current limits on associated neutralino-chargino production from CDF and D0 searches for SUSY-trilepton events. See text for details.

and neutralinos to trileptons (including electrons, muons and taus), as a function of the lightest stau mass, for various choices of μ and $\tan\beta$.

Limits from the CDF and D0 collaborations have been placed on the combined cross section for associated neutralino-chargino production and branching fractions to three leptons. In particular, D0 has published results for their search for events with three leptons (at least two of which are electrons or muons) plus missing energy using the first 320 pb^{-1} of data from Run II [13]. They find a rate consistent with the predictions of the Standard Model, and use this to place constraints on supersymmetry. CDF has published the results of their search for events with two like-sign leptons (electrons or muons) and missing energy using 1 fb^{-1} of data from Run II [14]. In this analysis, 13 events were observed, a slight excess compared to the 7.8 predicted by the Standard Model (corresponding to a chance probability of 7%). More recently, CDF has published the results of their combined search for associated neutralino-chargino production. These findings are consistent with Standard Model expectations [15]. In addition to these published results, a number of preliminary results from CDF [16] and D0 [17] searches for trilepton plus missing energy events have been reported.

In Fig. 3, we show the current limits from CDF and D0 in this channel. The limits from CDF are shown for two scenarios, labelled "mSUGRA" and "no-mixing". In the mSUGRA scenario, the masses of the staus are determined within the context of the mSUGRA model, which leads to the lightest stau being considerably less massive than the other sleptons and, in turn, to large branching fractions for chargino and neutralino decays to taus. In the no-mixing scenario, decays to taus, muons and electrons are approximately equally common. As taus are more difficult to identify than other leptons, the CDF limit in the mSUGRA scenario is considerably weaker than in the no-mixing case. Also shown is the D0 limit for the no-mixing scenario. It is more stringent than the limit from CDF, in part, because D0's result is slightly stronger than expected. By the end of Run II, the limits from each of these experiments are expected to improve by a factor of approximately 5 to 10.

III. THERMAL ABUNDANCE OF NEUTRALINOS WITHIN TEVATRON REACH

In R-parity conserving models in which the lightest neutralino is the lightest supersymmetric particle (LSP), such particles fall out of thermal equilibrium when the rate of Hubble expansion begins to dominate over their annihilation rate. The resulting density of neutralino dark matter in the universe today is related to its annihilation cross section:

$$\Omega_{\chi_1^0} h^2 \approx \frac{1.04 \times 10^9\, x_F}{M_{\rm Pl}\, \sqrt{g^\star}\, \langle \sigma v \rangle}, \tag{1}$$

where $\langle \sigma v \rangle$ is the thermally averaged neutralino–neutralino annihilation cross section, $g^\star$ is the number of relativistic degrees of freedom available at the temperature of freeze-out, and $x_F \equiv m_{\chi_1^0}/T_F$, where T_F is the temperature of freeze-out. For neutralinos (and other species of electroweak scale WIMPs), x_F falls in the range of 20-30. The thermally averaged annihilation cross section can be written as $\langle \sigma v \rangle \approx a + 3b/x_F$, where a and b are terms in the expansion $\sigma v = a + bv^2 + \vartheta(v^4)$.

The neutralino annihilation cross section depends on the details of the supersymmetric model, including the composition of the LSP and the masses and mixings of the exchanged sparticles and Higgs bosons. The four neutralinos of the MSSM are mixtures of the superpartners of the photon, Z and neutral Higgs bosons. The neutralino mass matrix is diagonalized into mass eigenstates by a unitary rotation $N^* M_{\chi^0} N^{-1}$. Hence, we can describe the lightest neutralino as a mixture of gauginos and higgsinos:

$$\chi_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1 + N_{14}\tilde{H}_2. \tag{2}$$

Although no accelerator bounds have been placed on the mass of the lightest neutralino directly [18], LEP II has placed a lower limit of 104 GeV on the mass of the lightest chargino, which is in turn related (at tree level) to M_2, $\tan\beta$ and μ,

$$m_{\chi_1^\pm} = \frac{1}{\sqrt{2}} \left[|M_2|^2 + |\mu|^2 + 2m_W^2 - \sqrt{(|M_2|^2 + |\mu|^2 + 2m_W^2)^2 - 4|\mu M_2 - m_W^2 \sin 2\beta|^2} \right]^{1/2}. \tag{3}$$

The LEP II bound, therefore, leads to a constraint of $|M_2|, |\mu| > 104$ GeV. Since we are interested in the case in which the $\chi_1^\pm$ and χ_2^0 are within the reach of the Tevatron, and yet significantly heavier than the lightest neutralino, we are forced to consider values of M_1 smaller than M_2 and $|\mu|$. If M_1 is considerably smaller than M_2 and $|\mu|$, the lightest neutralino will be largely bino-like, with a small higgsino admixture:

$$|N_{11}| \sim 1\,, \qquad \frac{|N_{13}|^2}{|N_{11}|^2} \approx \frac{m_Z^2\, \sin^2\theta_W\, \sin^2\beta}{|\mu|^2} \sim 0.01 \left(\frac{200\,\text{GeV}}{|\mu|} \right)^2, \qquad |N_{14}|^2 < |N_{13}|^2\,. \tag{4}$$

The mass of the lightest neutralino in this scenario is approximately given by

$$m_{\chi_1^0} \approx M_1 - \frac{m_Z^2 \sin^2\theta_W (M_1 + \mu \sin 2\beta)}{\mu^2 - M_1^2}. \tag{5}$$

In most supersymmetric models within the reach of trilepton searches at the Tevatron, the lightest neutralino typically annihilates somewhat inefficiently and thus is expected to be produced in the early universe with a thermal abundance in excess of the measured dark matter density. There are a number of possible exceptions to this conclusion, however. In particular:

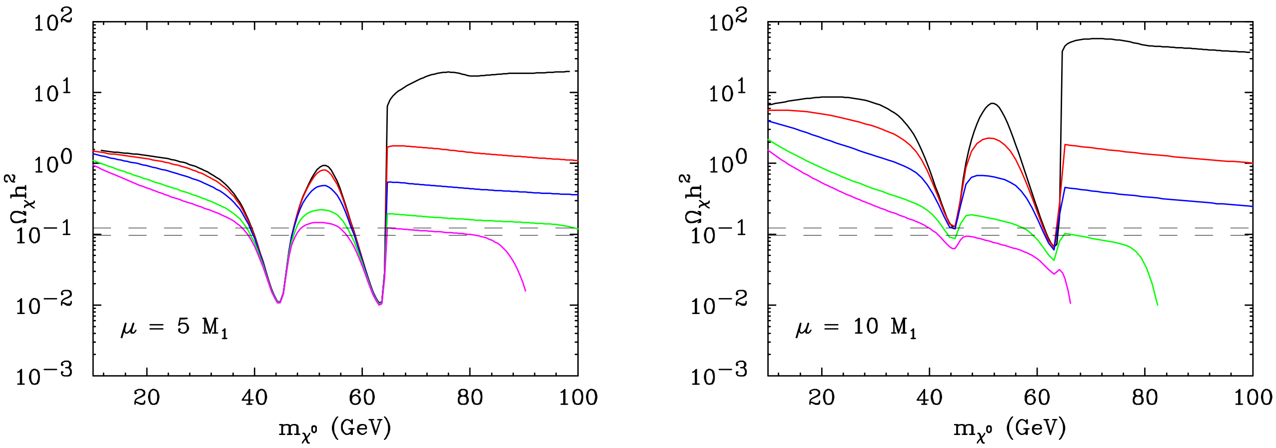

FIG. 4: The thermal neutralino relic abundance as a function of its mass for various values of the slepton masses. The slepton masses neglecting mixing are (from top to bottom) 1 TeV (black), 300 GeV (red), 200 GeV (blue), 140 GeV (green) and 120 GeV (magenta). Other parameters are $m_A = m_{\tilde{q}}$=1 TeV and $\tan\beta$=10. M_2 is either $2M_1$ or the lowest value consistent with the LEP chargino bound, whichever is greater. The trilinear couplings A_t and A_b are selected to maximize the light Higgs mass. In the left (right) frame, μ as set to $5M_1$ ($10M_1$). The horizontal dashed lines denote the dark matter abundance measured by WMAP [19]. The two dips correspond to the Z and light Higgs resonances.

– If the lightest neutralino is within a few GeV of the Z or h resonances ($2m_{\chi^0} \approx m_{Z,h}$), then annihilations through these channels can be very efficient, especially if the neutralino has a sizable higgsino fraction (*i.e.* moderate to small values of $|\mu|$). For example, the cross section for Z-mediated neutralino annihilation scales simply as the square of the difference of the two higgsino fractions, $(|N_{13}|^2 - |N_{14}|^2)^2$. Its effect can be seen in Fig. 4.

– Light sleptons, which are required in models within the reach of trilepton searches at the Tevatron, can also lead to efficient neutralino annihilation. In the extreme case, the lightest stau can be quasi-degenerate with the lightest neutralino, leading to highly efficient coannihilations. The effect of sleptons in the neutralino relic abundance calculation can be seen in Fig. 4. In this figure, we show the relic density as a function of the LSP mass, for various values (1000, 300, 200, 140 and 120 GeV) of the slepton masses.[1]

– If the currently (largely) unconstrained pseudoscalar Higgs boson A^0 is light enough and its couplings are large (large $\tan\beta$ and/or small $|\mu|$) then it will efficiently mediate neutralino annihilations. When not near the A^0-resonance, the cross section to down–type fermions through pseudoscalar Higgs exchange is proportional to $M_1^2 \tan^2\beta\, m_f^2/|\mu| m_A^4$. This contribution is most significant in the case of a mixed gaugino–higgsino with a light pseudoscalar Higgs and large $\tan\beta$.

From Fig. 4, it is obvious that light neutralinos will be overproduced in the early universe unless

[1] By "slepton mass" or $m_{\tilde{l}}$, we refer to a common mass for the selectrons, smuons and staus before off–diagonal terms in the mass matrices are accounted for. This quantity approximately corresponds to the selectron and smuon masses. The staus, in contrast, will depart somewhat from this value, $m_{\tilde{\tau}}^2 \sim m_{\tilde{l}}^2 \mp m_\tau (A_\tau - \mu\tan\beta)$.

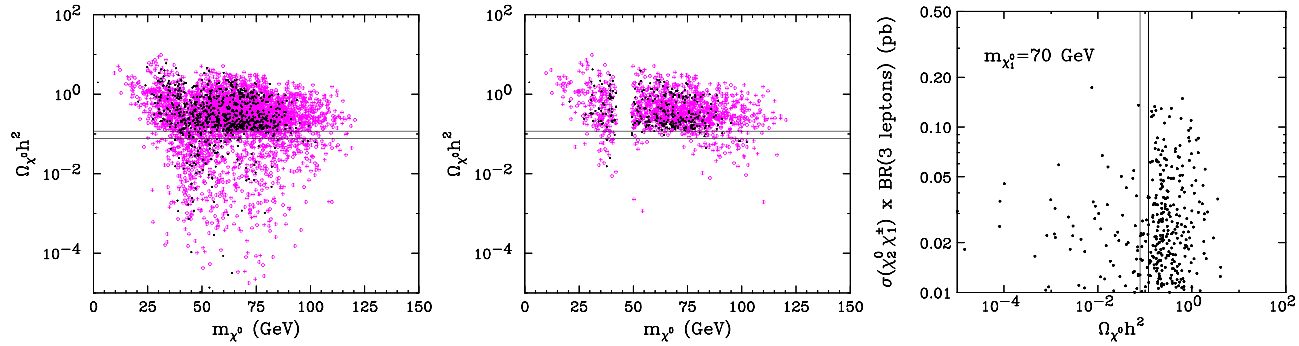

FIG. 5: Left panels: the thermal neutralino relic abundance as a function of the neutralino mass, in models within the reach of Tevatron trilepton searches. Dark points denote models which have already been excluded by the Tevatron trilepton searches, whereas the lighter points are within reach with 8 fb^{-1} of integrated luminosity. In the left frame, all of the models within the Tevatron reach are shown. In the center frame, we omit models with efficient Z, h or A^0-mediated dark matter annihilation (see text for details). In the right frame, we show the cross section times branching ratio for trilepton production at the tevatron as a function of the thermal relic abundance of neutralinos. In this frame we only show models with LSP masses within the range of 70±1 GeV.

the sleptons are light, the lightest neutralino's mass is within a few GeV of the Z or h resonances or pseudoscalar Higgs exchange provides a significant contribution to the annihilation cross section.

We demonstrate this further in Fig. 5, where we compare the relic abundances found in various models within the Tevatron reach. In this parameter scan, we vary the masses M_1, M_2, $m_{\tilde{l}}$, $m_{\tilde{q}}$, $|\mu|$ and m_A up to 1 TeV. Values of $\tan\beta$ within the range of 1 to 60 are considered. For simplicity, we assume the gluino mass to be $M_3 \approx 3.7 M_2$. All models shown in Fig. 5 satisfy all collider constraints on the chargino, slepton, squark and Higgs masses. The relic abundance we compute using DarkSUSY [20].

In the left frame of Fig. 5 we show all models found to be within the Tevatron reach. In the second frame we omit models with neutralinos annihilating through either a Z, h resonance or via an s-channel A^0 diagram. To quantify this selection we remove parameter points in which the lightest neutralino mass is within 7 GeV of the Z or h resonances, or with $(\tan\beta/10)^2/[(m_A/1\,\mathrm{TeV})^4\,(|\mu|/1\,\mathrm{TeV})] > 1$. These cuts overwhelmingly remove models with low relic densities, thus demonstrating that neutralino annihilation through Z or h resonances or through A^0-exchange are essentially required if dark matter is to avoid being overproduced in models within the reach of the Tevatron. Note however, that independent of the LSP mass well always find models which produce the correct relic density.

In the right frame of Fig. 5 we fix the LSP mass to 70 ± 1 GeV and show the correlation between the trilepton cross section times branching ratio versus the relic density. The mass of the produced neutralino and chargino is free. The fact that the majority of points tend towards overclosing the universe corresponds to a bias in the entire data sample, also seen in the left two panels of the same figure. We checked that independent of the LSP mass chosen there is indeed no visible correlation between the relic density and the Tevatron trilepton cross section in the MSSM.

IV. DIRECT DETECTION OF NEUTRALINOS IN TEVATRON REACH

Experiments such as XENON [21], CDMS [22] and many others [23] have over the last several years placed increasingly stringent limits on the elastic scattering cross section of WIMPs with nuclei. The neutralino's elastic scattering cross section with nuclei is given by

$$\sigma \approx \frac{4m_{\chi^0}^2 m_T^2}{\pi(m_{\chi^0}+m_T)^2}\,\left[Zf_p+(A-Z)f_n\right]^2\,, \tag{6}$$

where m_T is the target nuclei's mass, and Z and A are the atomic number and atomic mass of the nucleus. f_p and f_n are the neutralino's couplings to protons and neutrons, given by:

$$f_{p,n} = \sum_{q=u,d,s} f_{T_q}^{(p,n)} a_q \frac{m_{p,n}}{m_q} + \frac{2}{27} f_{TG}^{(p,n)} \sum_{q=c,b,t} a_q \frac{m_{p,n}}{m_q}, \tag{7}$$

where a_q are the neutralino-quark couplings and $f_{T_u}^{(p)} \approx 0.020 \pm 0.004$, $f_{T_d}^{(p)} \approx 0.026 \pm 0.005$, $f_{T_s}^{(p)} \approx 0.118 \pm 0.062$, $f_{T_u}^{(n)} \approx 0.014 \pm 0.003$, $f_{T_d}^{(n)} \approx 0.036 \pm 0.008$ and $f_{T_s}^{(n)} \approx 0.118 \pm 0.062$ [24].

The first term in the above equation corresponds to interactions with the quarks in the target nuclei, whereas the second term denotes interactions with the gluons in the target through a quark/squark loop diagram. $f_{TG}^{(p)}$ is given by $1 - f_{T_u}^{(p)} - f_{T_d}^{(p)} - f_{T_s}^{(p)} \approx 0.84$, and analogously, $f_{TG}^{(n)} \approx 0.83$.

The neutralino-quark coupling is given by [25]:

$$\begin{aligned} a_q \;=\; & -\frac{1}{2(m_{1i}^2-m_\chi^2)}\mathrm{Re}\left[(X_i)\,(Y_i)^*\right] - \frac{1}{2(m_{2i}^2-m_\chi^2)}\mathrm{Re}\left[(W_i)\,(V_i)^*\right] \\ & -\frac{g_2 m_q}{4 m_W B}\left[\mathrm{Re}\left(\delta_1[g_2 N_{12} - g_1 N_{11}]\right) DC\left(-\frac{1}{m_H^2}+\frac{1}{m_h^2}\right)\right. \\ & \left. +\mathrm{Re}\left(\delta_2[g_2 N_{12} - g_1 N_{11}]\right)\left(\frac{D^2}{m_h^2}+\frac{C^2}{m_H^2}\right)\right], \end{aligned} \tag{8}$$

where

$$\begin{aligned} X_i &\equiv \eta_{11}^* \frac{g_2 m_q N_{1,5-i}^*}{2 m_W B} - \eta_{12}^* e_i g_1 N_{11}^*, \\ Y_i &\equiv \eta_{11}^* \left(\frac{y_i}{2} g_1 N_{11} + g_2 T_{3i} N_{12}\right) + \eta_{12}^* \frac{g_2 m_q N_{1,5-i}}{2 m_W B}, \\ W_i &\equiv \eta_{21}^* \frac{g_2 m_q N_{1,5-i}^*}{2 m_W B} - \eta_{22}^* e_i g_1 N_{11}^*, \\ V_i &\equiv \eta_{22}^* \frac{g_2 m_q N_{1,5-i}}{2 m_W B} + \eta_{21}^* \left(\frac{y_i}{2} g_1 N_{11}, + g_2 T_{3i} N_{12}\right). \end{aligned} \tag{9}$$

In these expressions, $i = 1, 2$ denote up and down-type quarks, respectively. m_{1i}, m_{2i} denote the squark mass eigenvalues and η is the matrix which diagonalizes the squark mass matrices. y_i, T_{3i} and e_i denote hypercharge, isospin and electric charge of the quarks. For scattering off of up-type quarks $\delta_1 = N_{13}, \delta_2 = N_{14}, B = \sin\beta, C = \sin\alpha, D = \cos\alpha$, whereas for down-type quarks $\delta_1 = N_{14}, \delta_2 = -N_{13}, B = \cos\beta, C = \cos\alpha, D = -\sin\alpha$. α is the mixing angle in the Higgs sector.

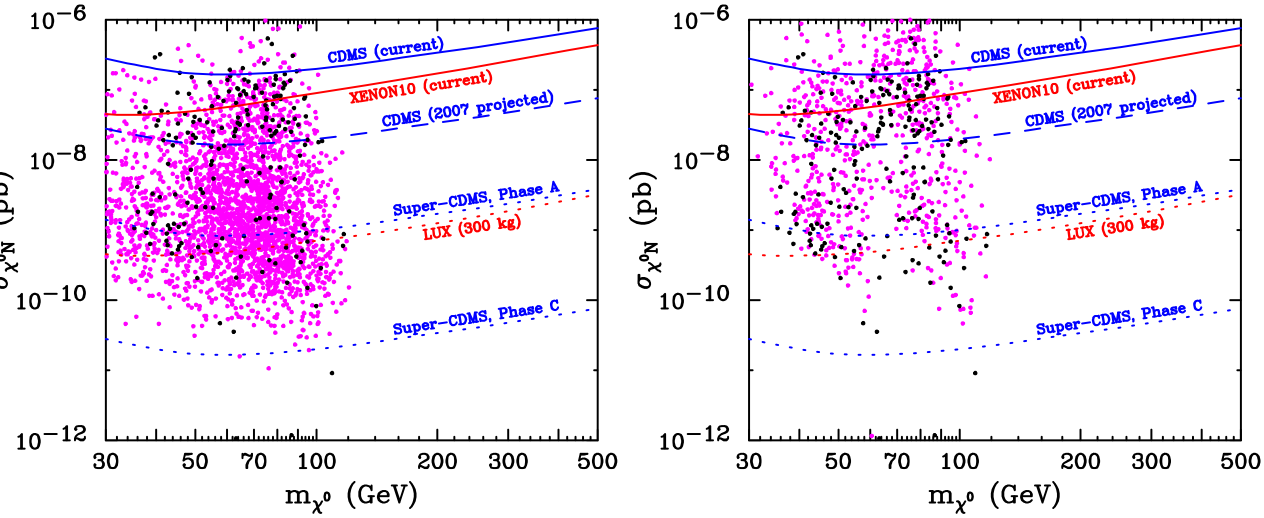

FIG. 6: The neutralino's elastic scattering cross section with nucleons, as a function of its mass, in model which are within the reach of trilepton searches at the Tevatron with 8 fb^{-1} luminosity. In both frames, the dark points represent models which are predicted to generate a thermal density of dark matter within the range measured by WMAP [19]. In the left (right) frame, the lighter points represent models which predict a larger (smaller) dark matter density than is measured.

In Fig. 6, we plot the neutralino-nucleon elastic scattering cross section found in those models which are within the 8 fb^{-1} reach of the Tevatron's trilepton search. In each frame, the dark points correspond to models which predict a thermal abundance of neutralino dark matter within the range measured by WMAP [19]. The lighter points represent models with too much (left) or too little (right) dark matter relative to the measured abundance. As expected from the different composition patterns of the neutralinos, we find a very large range of cross sections, varying from about 10^{-6} to 10^{-11} pb. Models which predict an abundance of dark matter below the measured value tend to have somewhat larger elastic scattering cross sections with nuclei. This is due to the coupling to heavy MSSM Higgs bosons which can both mediate neutralino annihilation and elastic scattering processes. Most models with the observed relic density fall in the upper portion of the elastic cross section range. In particular, the majority of them are within the reach of CDMS's current run (labelled CDMS 2007). This is not the case for a typical scan over the entire MSSM parameter space, which consists mostly of models beyond the Tevatron's reach (see, for example, Ref. [26]).

The reasons for the favorable direct detection prospects among models within the reach of the Tevatron are somewhat subtle. In the case of a neutralino annihilating in the early universe primarily through a Z or h resonance, little can be said regarding the prospects for direct detection. Furthermore, in models which annihilate largely through slepton exchange in the early universe (or through coannihilations with sleptons), the elastic scattering cross section is likely to be suppressed. In many of the models within the reach of the Tevatron, however, the neutralino annihilation cross section is dominated by pseudoscalar Higgs exchange. In these models, which feature moderate to large values of $\tan\beta$ and somewhat light pseudoscalar Higgs masses, the elastic scattering cross section is typically dominated by the exchange of the heavy scalar Higgs, H, with strange and bottom quarks, leading to a neutralino-nucleon cross section

of:

$$\sigma_{\chi N} \sim \frac{g_1^2 g_2^2}{4\pi} \, \frac{1}{m_W^2 \cos^2\beta} \, \frac{m_N^4}{m_H^4} \, |N_{11}|^2 |N_{13}|^2 \, \left(f_{T_s} + \frac{2}{27} f_{TG} \right)^2 . \tag{10}$$

The similarity $m_H \sim m_A$ is of course not an artefact of a SUSY–breaking assumption, but a generic feature of the two–Higgs–doublet model. Because in a large fraction of these models the combination of $\tan^2\beta/m_A^4|\mu|$ is large in order to generate an acceptable relic abundance, the direct detection rates also have a tendency to be larger compared to those found in a more general sample of supersymmetric models.

V. OUTLOOK

In this article, we have studied the cosmological implications of supersymmetric models within the reach of searches for associated neutralino-chargino production at Run II of the Tevatron. We have analyzed how results from this Tevatron search channel might impact the prospects for direct searches for neutralino dark matter. Although there is not a particularly direct or obvious connection between these two experimental programs, it is important to consider how to exploit the interplay between collider and astrophysical searches for supersymmetry.

Supersymmetric models whose rate of trilepton events from associated chargino-neutralino production is within the reach of the Tevatron have some rather peculiar features. In particular, they contain light neutralinos which either annihilate through a Z or h resonance, through pseudoscalar Higgs exchange, or via very light sleptons. Therefore, for models in which the lightest neutralino is not within a few GeV of $m_Z/2$ or $m_h/2$, the heavy Higgs bosons A, H tend to be light and values of $\tan\beta$ are typically moderate to large. These neutralinos will also show a non–negligible higgsino fraction. These features lead to larger than average elastic scattering cross sections with nuclei (which is dominated by H exchange), and high rates in underground direct dark matter experiments. This means that if the Tevatron detects trilepton events from associated neutralino–chargino production, the near future prospects for the direct detection of neutralino dark matter are expected to be promising.

The absense of more distinct parameter correlations means that the collider and the cosmological analyses of the MSSM neutralino and chargino sector probe different properties of the supersymmetric spectrum. This is different from the case of, for example, gravity–mediated SUSY breaking. Looking at the TeV–scale MSSM this implies that the information gained in dark matter searches is largely orthogonal to the information which could be obtained from collider searches. Only by combining many sets of information from many different experimental channels will it become possible to construct with confidence a consistent picture of the TeV–scale Lagrangian [27].

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